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THE Dy163-Ho163 BRANCHING: AN s-PROCESS BAROMETER *

H. Beer and G. Walter
Kernforschungszentrum Karlsruhe, IK III,
P.O.B. 3640, D-7500 Karlsruhe 1, FRG

R.L. Macklin
Oak-Ridge National Laboratory, P.O.B. X, Oak-Ridge, TN 37831 **

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ABSTRACT

The neutron capture cross sections of Dy163 and Er164 have been measured to analyse the s-process branching at Dy163 - Ho163. The reproduction of the s-process abundance of Er164 via this branching is sensitive to temperature kT, neutron density, and electron density n_e. The calculations using information from other branchings on kT and the neutron density n_n give constraints for n_e at the site of the s-process.

INTRODUCTION

In order to obtain information about the site of the slow neutron capture nucleosynthesis (s-process) which means knowledge of the astrophysical parameters of temperature, neutron flux and mass density branchings of the synthesis path at beta unstable nuclei have to be examined. The Dy163 - Ho163 branching is unique as it provides information on all three important astrophysical parameters: s-process temperature, and neutron and electron density. The sensitivity to the electron density is especially interesting as it allows for a calculation of the mass density in the He-shell, the presumed site of the s-process.

MEASUREMENTS

The neutron capture cross section measurements on Dy163 and Er164 were carried out at the Oak-Ridge Linear Accelerator (ORELA) and the Karlsruhe 3.75 MV pulsed Van de Graaff (VDG). The Dy163 cross section measurement was determined using the time-of-flight technique. The measurements were performed both at ORELA and the VDG. The excellent agreement of the two data sets is a secure check of systematic uncertainties (Fig.1). The Er164 cross section was determined with the activation technique at the VDG by counting of the K x-ray activity of Er165 (10.3h) relative to the activity of the 412 keV gamma line of Au198 (2.69d). The gamma activity was recorded with a gamma-x Ge-detector (efficiency: 7.2% ; resolution at 1.33 MeV: 1.6 keV) with good response at the very low x-ray energy of Ho as well as at the energy of the Au198 line. More details about the time-of-flight facilities and the activation technique can be found elsewhere[1,2]. The sample characteristics and the results are summarized in Tables I-II.

ANALYSIS

Under the stellar s-process conditions Dy163, a stable isotope on the synthesis path becomes radioactive so that competion between beta de-

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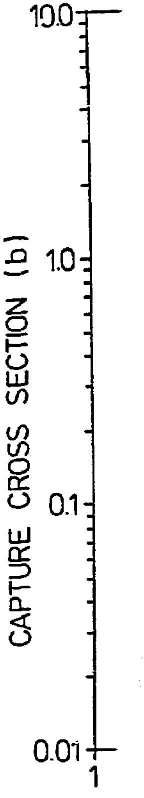

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cay and neutron capture allows for an s-process synthesis of Er164 via neutron capture of Ho163 and subsequent beta decay of Ho164 to Er164. The surprising fact that Dy163 in stellar interiors might be radioactive is due to the small Q-value between Ho163 and Dy163 of only 2.3 keV[3,4] which makes possible bound state beta decay and facilitates excited state beta decay. The dependency of Dy163, Ho163, and Ho164 half-lives on temperature kT and electron density has been treated in ref.[5,6] In order to reproduce the Er164 s-process abundance (solar minus p-process abundance estimated via Er162) the half-lives of Dy163, Ho163, and Ho164 and the capture cross sections of Dy163, Ho163 and Er164 are the indispensable input parameters for our branching calculation. As the astrophysical parameters, temperature and neutron density, are known from other branchings[1] the electron density could be adjusted to yield the s-process abundance of Er164. Fig.2 shows the σ-times-abundance Ns curve at the site of the Dy163 branching to illustrate our calculations. Fig.3 gives the range of allowed values for kT, n_n and n_e.

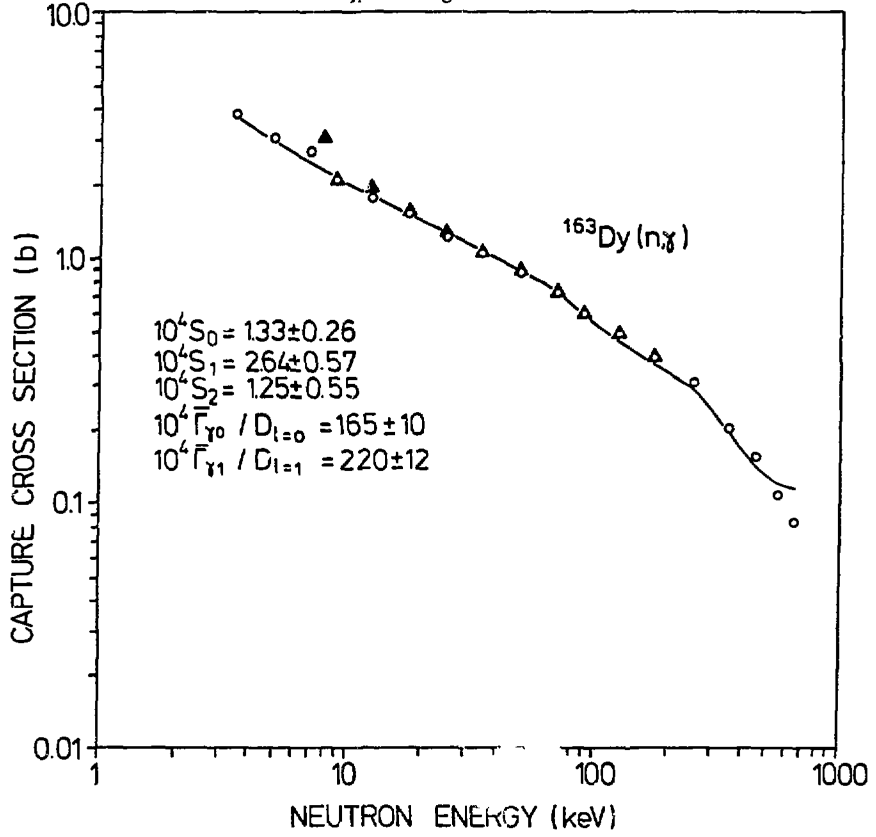

Fig.1 Effective cross section for Dy163(n,γ). The curve is a statistical model fit to the data[8] with the indicated values for s-,p-,and

d-wave strength functions, radiation widths and level spacings. Circles are data from ORELA, triangles from VDG.

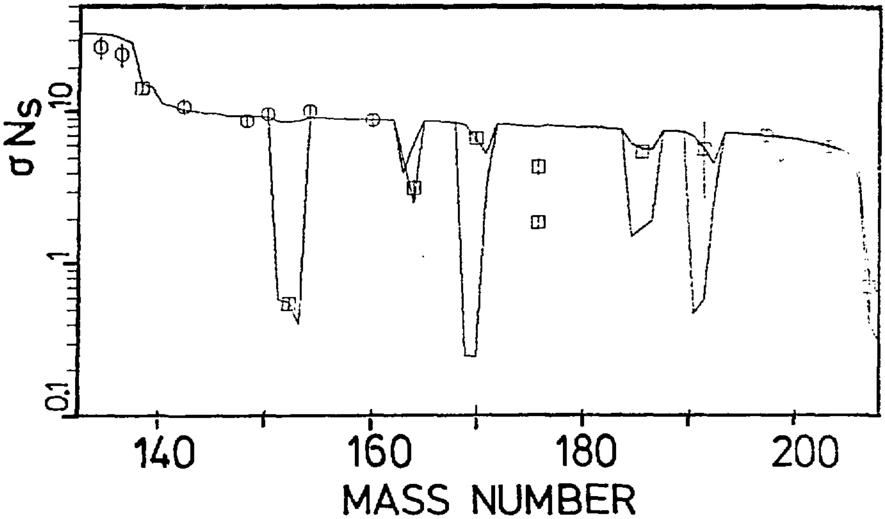

Fig.2 The product of capture cross section σ and s-process abundance Ns as a function of mass number. The symbols are empirical data. The solid line is the s-process calculation with the exponential distribution of neutron exposures. At Pb and Bi an additional exposure component has been added.[9] At the branchings kT, n_n, and n_e are adjusted to reproduce Gd152, Er164, Os186, and Pt192. Only in the case of Er164 is the branching sensitive to the electron density n_e.

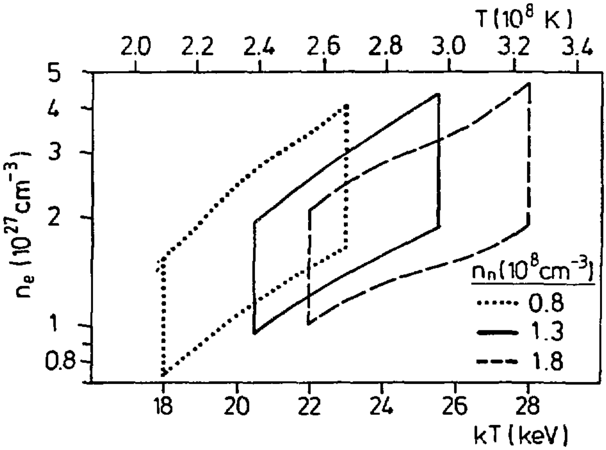

Fig.3 The curves circumscribe allowed ranges of n_e and kT for three different neutron densities. The variation of n_e is due to the various uncertainties in the Dy163-Ho163 branching and the range of kT= 18-28 keV and n_n=(0.8-1.8) 10^8/cm^3 from the other branchings.[1]

CONCLUSIONS

There is a simple relation between electron density and the mass density ρ in the He-shell of a red giant star which is the presumed site of s-process nucleosynthesis. We can assume that He is totally ionized and the electrons are still not degenerate. Therefore $n_e = \frac{1}{2}\rho N_o$ (No: Avogadro's number) is a measure of the mass density in the He-shell. The mass densities found (2600-13000 g/cm^3) are higher than currently assumed (2000 g/cm^3), but still compatible for example with Ulrich's s-process model of a $5M_\odot$ star[7]($\rho \leq 3500$ g/cm^3).

Table I Sample characteristics and Maxwellian averaged capture cross section σ at the thermal energy kT=30 keV.

Sample	Diameter (mm)	Weight (mg)	% Isotopic composition	σ(mb) at kT=30 keV
Dy_2O_3	15	907.39	96.85 Dy163	1153±44(VDG) 1130±45(ORELA)
Er-metal	6	8.30	1.61 Er164	714±61(VDG)

Table II Dy163(n,γ) resonance capture areas. The stated uncertainty is statistical only.

Eo (eV)	$g\Gamma_n\Gamma_\gamma/\Gamma$ (meV)	Eo (eV)	$g\Gamma_n\Gamma_\gamma/\Gamma$ (meV)
2651	19.4±1.9	2732	28.6±1.7
2657	66.6±0.8	2743	36.9±1.9
2665	12.2±1.7	2758	29.4±1.8
2675	35.2±2.1	2768	35.8±2.1
2681	34.9±2.1	2776	31.3±2.3
2686	17.6±2.0	2781	30.4±2.9
2700	24.1±1.7	2785	70.3±0.9
2713	65.7±0.7		

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